

## Water quality and its interlinkages with the Sustainable Development Goals

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## **Abstract**

Interlinkages among the Sustainable Development Goals (SDGs) lead to important trade-offs and synergies among the goals and their underlying targets. The aim of this paper is to review the role of water quality as an agent of interlinkages among the SDGs. It was found that there are a small number of explicit interconnections, but many more inferred interlinkages between water quality and various targets. A review of case studies showed that interlinkages operate from the municipal to near global scales, that their importance is likely to increase in developing countries, and that new SDG indicators are needed to monitor them. The analysis identifies many different SDG target areas where a combined effort between the water quality community and other sectors would bring mutual benefits in achieving the water quality and other targets.

## **Highlights**

- This paper identifies interlinkages of water quality with SDGs based on evidence from the literature.
- Water quality plays different roles in SDG interlinkages – as driver, as intermediary, as loser in a trade-off situation, or as beneficiary of a synergy.
- New indicators are needed to track water quality interlinkages.
- Many more synergies than trade-offs were identified; these provide opportunities for multi-sectoral or “nexus” policies that simultaneously advance both the water quality and other SDG targets.

## **Introduction**

The UN Sustainable Development Goals (SDGs) are ambitious and globally comprehensive, and unsurprisingly, will entail substantial investments. The UN Conference on Trade and Development estimates this figure to be around 5 to 7 trillion USD per year (UNCTAD, 2014).

In order to reduce costs, countries are discussing ways to “improve the efficiency of implementation”. One approach, expressed in the Ministerial Declaration of the 2018 High Level Political Forum on Sustainable Development countries is to “...pay particular attention to leveraging synergies and co-benefits across all dimensions of sustainable development, while avoiding or minimizing trade-offs.”(ECOSOC, 2018). The reasoning here is that trade-offs lead to “inefficiencies”, whereas synergies are an efficient way to advance two or more goals at the same time. (Anon., 2018).

But acting on synergies and trade-offs requires not only political will but also knowledge about their origin and characteristics.

The objective of the paper is to present a review of interlinkages between the water quality target of the SDGs and other SDG targets. More generally, it aims to investigate the role of water quality as an agent of trade-offs and synergies among the SDGs. Key questions addressed are: What are the characteristics of interlinkages? How can the significance of interlinkages be assessed? What is the adequacy of official SDG indicators for tracking water quality interlinkages?

Findings from this paper can be used to identify cross-sectoral actions that advance both the water quality target and other targets at the same time. They can also help steer water quality research and monitoring that simultaneously supports the water quality target and other SDG targets.

This paper focuses on water quality for two main reasons. First, because it is explicitly included in the SDGs as Target 6.3: “By 2030, improve water quality by:

- reducing pollution,
- eliminating dumping and minimizing release of hazardous chemicals and materials,
- halving the proportion of untreated wastewater, and
- substantially increasing recycling and safe reuse globally.” (bullets added).

(This will be referred to as the “water quality target” in subsequent text.)

The second reason is that good water quality is globally significant; it satisfies the needs of society for clean water (drinking water, cooking water, hygienic uses, and industrial uses); it makes a vital contribution to ecosystem services such as subsistence, commercial and recreational fishing; and ensures the safe use of surface waters for recreational purposes, hygiene, and household activities (Keeler, et al. 2014; Schwarzenbach, et al. 2010; Adeyemo, 2003). Lack of water quality is also a major contributor to water scarcity (van Vleet et al. 2017).

This work is intended to complement previous efforts to investigate SDG interlinkages (e.g. Griggs et al. 2017; Pradhan et al. 2017; UN-Water, 2017; Scharlemann et al. 2016) by “drilling down” on a single target. Griggs et al. 2017 analyze the interaction between SDGs 2, 3, 7 and 17 and other SDGs at the target-level. They use expert judgement and an arbitrary seven point scale to rank the importance and direction of the interactions. UN-Water (2017) “highlight[s] the interdependency between the targets under Goal 6 ... and other Goals and targets ...” Using expert judgement, links (interlinkages) are identified and classified as either a “main synergy” or causing a “potential conflict”. Scharlemann et al. (2016) use expert judgement to analyze the interactions among all goals (at the goal level) and color-code the interactions according to the relative influence of one goal on another. The accent of their analysis is on human-environment interactions. Pradhan et al. (2017) take a different approach to the other cited studies and perform a statistical analysis of historical SDG indicator data (on the country- and global scale) to uncover synergies and trade-offs between SDGs. As compared to these studies, the present work focuses on a single target and uses evidence from the literature to articulate interlinkages between water quality and other SDGs. It complements the review of Ezbakhe, 2018 by examining many other aspects of water quality interlinkages including their scale, their classification, the issue of indicators, and how to minimize trade-offs.

The paper is organized as follows: The first part provides an inventory of the interlinkages between water quality and SDGs at the level of their underlying targets. This inventory is derived from a multi-disciplinary review of the literature, using a key phrase search containing water quality and key concepts mentioned in the SDG targets. Since the literature on SDG interlinkages is relatively small, very few articles are published that specifically address water

quality – SDG interlinkages. Therefore the author also reviewed the large body of literature concerned with interconnections between water quality and SDG-related topics, even though this literature does not explicitly refer to the global goals. For example, Table 1 identifies the interlinkages between water quality and Goal 1 (No Poverty) drawing on the literature about water and poverty, which is relevant to the SDGs, but does not specifically refer to them. Also, the author does not investigate the “null hypothesis”, i.e. that no interlinkages exist.

The second part of the paper describes four “case studies” of interlinkages among SDGs where water quality is either directly or indirectly affected or involved. The aim of this section is to investigate how interlinkages emerge from systems relationships. The author reviews the dimensions and significance of these trade-offs, and discusses how they can be minimized and in some cases transformed to synergies.

The final part highlights general findings from the inventory and case studies. Figure 1 provides a visual guide for many of the interlinkages described in the text.

### **An Inventory of Interlinkages**

Table 1 presents a catalogue of interlinkages, with an estimation of whether they result in a trade-off or synergy. In this paper, a trade-off is a condition by which an action to achieve one goal or target makes it more difficult to achieve one or more other goals or targets. For example, if the area of conventional agriculture is expanded to achieve Goal 2 (Zero hunger), it is likely that water pollution will also increase, making it more difficult to achieve the water quality target. This is considered a trade-off between Goal 2 and the water quality target. Note that the direction of influence is important here; expanding cropland leads to more pollution, not the other way around.

In this paper, a synergy is a condition by which an action to achieve one goal helps achieve one or more other goals. An example of a synergy would be a major programme to augment nitrogen use efficiency on cropland which can increase yields while also reducing water pollution and gaining other benefits. This action would set up a synergy between Goal 2 (Zero hunger), the water quality target, and other goals and targets. Note that in this paper trade-offs or synergies among SDGs can only arise from a change in the status quo, consistent with the idea that achieving goals and targets imply a change in the status quo.

Table 1 also distinguishes between explicit and inferred interlinkages. “Explicit” interlinkages are those in which the SDG text explicitly refers to water quality or concepts directly connected with water quality. For example, Target 15.1 mentions “inland freshwater ecosystems” which have a direct connection to water quality. “Inferred” interlinkages are those that are not explicit, but can be inferred from evidence in the literature. The example given above in which the area of conventional agriculture expands and is inferred (based on literature evidence) to cause additional water pollution is a case of an inferred interlinkage between Goal 2 and the water quality target.

Table 1 also notes whether an indicator from the UN’s SDG indicator framework (IAEG-SDGs, 2017) is applicable for tracking the interlinkage. This and other issues raised by results from Table 1 are taken up later in the Discussion section.

### **Four Case Studies**

As an elaboration of the overview in Table 1, the next section examines four particular interlinkages more closely. They were selected because they illustrate how inferred interlinkages can arise through system relationships, how they can vary in scale, and how they

are mediated by human actions. Furthermore, they were selected to illustrate interlinkages involving a wide range of different water quality issues.

The case studies elucidate the significance of the interlinkages, how they lead to trade-offs, and how these trade-offs can be minimized.

### ***Case Study 1: The energy costs of wastewater treatment***

Although there are many different options for protecting the quality of water, end-of-the-pipe treatment of wastewater remains an important option for achieving the water quality target, particularly “halving the proportion of untreated wastewater”. A trade-off arises because treatment facilities use considerable amounts of energy to pump wastewater, run their equipment, and illuminate and heat the facilities (Figure 1). Hence, if efforts to achieve the water quality target include an increase in the volume of treated wastewater, then energy use for this purpose will also increase, perhaps making it more difficult to achieve targets under Goal 7 (Affordable and clean energy).

Total electricity requirements for treating one million liters of wastewater are approximately 250 to 500 kWh, depending on the type of treatment (WWAP, 2012). To put these figures into perspective, the amount of electricity used to treat wastewater in a city of one million people in Africa would be equivalent to the per capita electricity consumption of 40,000 people.<sup>1</sup> In the US, costs of energy consumption for wastewater and water utilities are already 30 to 60% of the total energy bill of municipalities (US EPA, 2008).

To achieve the water quality target it is likely that the capacity of wastewater treatment must be vastly increased; roughly 80% of collected wastewater in developing countries is not yet treated before being discharged into receiving waters (UN-Water, 2011) and the total volume of wastewater could increase by a factor of 3.5 to 4.5 in Sub Saharan Africa and 2 to 3 in Latin America between 1995 and 2050 (Alcamo et al., 2005). Hence, the trade-off between the water quality target and Goal 7 is expected to intensify. But this trade-off, as with all trade-offs identified in this paper, is not inexorable. Trade-offs usually arise from “business as usual” behavior, and they can be minimized by departing from this behavior. For example, several options exist to decouple energy use from an increase in capacity of wastewater treatment. At the facilities themselves, reductions in energy use can be realized by downsizing pumps and motors and optimizing the amount of air delivered to the aeration process (Daw et al. 2011). Biogas produced as a by-product of the treatment process is already often used at facilities to reduce external energy costs.

These options all assume that conventional wastewater treatment facilities will continue to be used to control water pollution. However, other options with lower energy requirements, such as “constructed wetlands (Vymazal, 2010) are also available. But these and other alternatives to conventional treatment may have additional disadvantages and advantages that need to be considered. Constructed wetlands, for example, sometimes cause odour problems, but also provide new wildlife habitat (Rousseau et al. 2009).

From a systems perspective, another way to reduce overall energy use is to reduce the production of wastewater at the source through recycling and reuse. This action is closely

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<sup>1</sup> Assuming  $250 \text{ kWh} / 10^6 \text{ l} \times 150 \text{ l/c/d} \times 365 \text{ d/yr} \times 1 \text{ M people} = 13,687,500 \text{ kWh/yr}$  to treat wastewater from 1 M people (this calculation uses the bottom of the range of 250-500 kWh/10<sup>6</sup> l from USA as referenced in the text). Ghana’s per capita electricity consumption in 2011 was 344 kWh/cap/yr. Therefore the electricity consumption of wastewater treatment in a city of one million is equivalent to  $13,687,500 \text{ kWh/yr} / 344 \text{ kWh/cap/yr} = 39,789 \text{ people}$

related to the objective of “substantially increasing recycling and safe reuse globally” embodied in the water quality target. Another option from the systems perspective is to consider the overall energy balances of centralized versus de-centralized models of wastewater treatment. Also relevant here, and closely related to the systems perspective, are “Nexus” approaches that promote management across sectors, for example across water, land and waste sectors (Hülsmann and Ardakanian, 2018; Alcamo, 2015).

To sum up, the energy needs for wastewater treatment are considerable and increasing particularly in developing countries, but there are also many options for minimising this trade-off.

### ***Case Study 2. Irrigated cropland causing salinity pollution***

While there are numerous connections between water quality and the food system, this section focuses on the important connection between water quality and irrigated food production. Irrigated cropland makes a well-known disproportionate contribution to world food supply by producing 40% of the world’s food on only 20% of all agricultural land (Kadiresan and Khanal (2018). To cover growing food demands, the Food and Agriculture Organisation (FAO) projects a 10% expansion of irrigated area in developing countries between 2005 and 2050 (FAO, 2012).

The connection between water quality and irrigated crop production goes in two directions. Firstly, farmers withdraw water from surface or subsurface sources and apply it to cropland where it picks up salts from soils, as well as residues of applied fertilizers and pesticides and other pollutants. These pollutants drain from farmland and cause salinity and other pollution in downstream stretches of rivers or other waterways (water quality is also degraded because there is less remaining river flow to dilute pollutants after it has been diverted upstream into irrigation canals). Hence, a trade-off arises, in that an expansion of irrigated agriculture may help achieve Goal 2 but is likely to hinder the achievement of the water quality target. Since the impacts of irrigation usually occur within a river basin, the trade-off can be said to operate on the river basin scale.

In the other direction, most irrigated crops require a water supply low in salts, and are therefore unable to use saline-polluted water supplies (Irrigation water must have low enough salinity levels to avoid the accumulation of salts in the crop root zone which can interfere with the take up of water by the crop (Grattan, 2002)). Hence, it sometimes occurs that runoff from irrigation leads to such high levels of salinity downstream that river water is no longer suitable for further irrigation. From a systems perspective, the expansion of irrigated cropping could set up a self-limiting feedback (Figure 1).

How important could this feedback be? UNEP (2016) estimates that about 10% of all river stretches in Asia, Africa and Latin America have salinity levels that partly or completely restrict their use for irrigation. The main source of this contamination is irrigation runoff itself. Floerke et al. (2016) estimate that more than 49 million ha under irrigated food production in Asia are located along river stretches with this same high level of salinity.

How can these trade-offs be minimized? One approach is to reduce runoff by improving the water use efficiency of irrigation projects. A disadvantage of this is the economic “rebound effect” which means that improving irrigation efficiency can actually lead to an expansion of irrigation area. This is because farmers perceive that efficiency improvements give them a higher profit margin (Ward and Pulido-Velazquez, 2008). Collecting and desalinating irrigation runoff is not feasible on the large-scale because of the large volume of irrigation

wastewater, and the high costs of desalination (Burn et al. 2015). As a result, Hopkins et al. (2007) believe the only economic approach is dilution, which requires a new source of freshwater in areas that are by definition dry. Over the long-term, a larger systems-view will be needed to resolve the issue of irrigation and its impacts. Comprehensive solutions need to be considered such as shifting some types of food production to rainfed areas and importing more food to drier areas.

### ***Case Study 3. Bioenergy cropping leads to coastal eutrophication***

Although bioenergy development has become a lower priority in Europe, it continues to receive strong official support elsewhere and is being discussed as part of the global strategy to achieve Goal 7 (Affordable and clean energy) (IRENA et al. 2018). Scenarios from the International Energy Agency and Food and Agriculture Organization estimate an expansion from 13.8 to 34.5-58.5 million hectares for bioenergy cropland between 2004 and 2030 (FAO, 2008).

As with virtually all industrial processes, wastewater is produced at various points in the bioenergy supply chain, and this sometimes leads to water pollution, setting up a trade-off between energy and water quality targets. This section focuses on the part of the chain having to do with water quality impacts of bioenergy crops. As an example, growing maize and soybean for ethanol production in the United States results in runoff of fertilizer to the Mississippi River and its tributaries, amounting to about 52% of the nitrogen loading into the Gulf of Mexico (Alexander et al. 2008). This causes eutrophication in the northern coastal waters of the Gulf, a process by which the water environment is “over-enriched” by nutrients which, in turn, stimulates the excessive growth of algae. At certain times of the year, large populations of algae die off rapidly and their decomposition depletes the oxygen needed by aquatic organisms. This creates a large hypoxic (critically low in oxygen) zone of around 20,700 km<sup>2</sup> in the lower depths of the Gulf, devoid of most aquatic life (Rabalais et al., 2002). This is only one of several such hypoxic zones found in coastal areas around the world. The extent of these areas is expected to increase globally as nutrient loads increase and as other global changes occur (Rabalais et al., 2009). (We note that nutrient runoff from bioenergy crop cultivation can also be a cause of eutrophication of lakes and other freshwater ecosystems.)

In this example, the production of bioenergy (related to Goal 7) sets up a large-scale trade-off with Goal 14 (Life below water) (Figure 1). Two targets are particularly affected – Target 14.1 (“prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution”) and Target 14.2 (“sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts”). In this case, water quality acts as an intermediary of the interlinkage between bioenergy production and marine conservation.

The direct approach to mitigating this particular impact of bioenergy on coastal and freshwater eutrophication would be to reduce the runoff of fertilizers at the source, and thereby alleviate the outflow of nitrogen to the coastal zone and sensitive freshwater areas.

A comprehensive strategy to do this is to increase the “nitrogen use efficiency” (NUE) of crops through better nutrient management, together with other measures such as plant breeding, improved irrigation and drainage, and improved pest management. In some cases using livestock waste rather than artificial fertilizer can also increase this efficiency. These combined measures have the potential to augment crop yield, while reducing the amount of nitrogen needed by crops as well as its losses (UNEP, 2013; Chen et al. 2011). A likely result would be a reduction in the loading of nitrogen to the coastal zone.

Improving NUE is a good example of an action that realizes synergies among several SDGs. Apart from reducing nitrogen runoff and lessening coastal eutrophication, it also reduces health-threatening nitrate in groundwater and therefore addresses local aspects of the water quality target and Goal 3 (Global health and well-being); by raising crop yields it helps achieve Goal 2 (Zero hunger); and by reducing nitrous oxide emissions it also addresses Goal 13 (Climate action).

#### ***Case Study 4. Water quality and the risk of antimicrobial resistance***

Goal 3 has important targets to combat disease and these have a close connection to water quality (Table 1).

A less obvious connection, but one receiving increasing attention, has to do with the overuse of antibiotics and other medicines used for addressing illnesses of humans and animals. This overuse has caused the spread of antimicrobial resistance (AMR), the ability of bacteria and other organisms to resist elimination by conventional antibiotics and other antimicrobial agents. There is growing evidence that the water environment plays an important role in AMR in several ways: (i) by accumulating residuals of antibiotics and antimicrobial agents, (ii) collecting resistant bacteria and other organisms from waste or wastewater of humans and livestock, (iii) serving as a channel for the production and spread of these organisms, and (iv) increasing exposure of people and livestock to resistant organisms (WHO, 2014; Baquero et al. 2008).

Efforts to combat illness under Goal 3 are expected to increase health care and stimulate antibiotic use, especially in developing countries. Global consumption of antibiotics already increased by 65% between 2000 and 2015, mostly in developing countries.

AMR also has an important connection with the food production targets under Goal 2 (Zero hunger) because a substantial percentage of current antibiotics go to treating farm animals and for disease prevention in aquaculture. Van Boeckel et al. (2015) estimate a 67% increase worldwide in antimicrobial use for livestock between 2010 and 2030. Residuals of antibiotics from livestock and aquaculture are also major sources of antibiotics in the water environment. (Baquero et al. 2008).

Hence, some actions towards achieving Goals 2 and 3 set up the water quality target as a loser in a trade-off situation. This trade-off operates over the spatial scale of a river basin since the source of river concentrations of antibiotics is usually from within the basin (e.g. Watkinson et al. 2009).

Equally important, contamination of surface waters with resistant organisms and antimicrobial agents will intensify the problem of AMR, setting up a negative feedback to Goal 3 (Figure 1).

To reduce this trade-off, it is necessary to reduce the flux of antibiotics and resistant organisms to the water environment. Among the options suggested by Pruden et al. (2013) are:

- Reducing antibiotic use at the source by improving the health care of people (reducing the need for antibiotics), not over-prescribing pharmaceuticals for people; and not over-using antibiotics on farm animals and in aquaculture facilities.
- Controlling their entry into the water environment by expanding or upgrading wastewater treatment.

From a systems point of view, these solutions arise by focusing on the health care – environment system. If system boundaries are expanded, other solutions arise. For example, if Goal 7 (Affordable and clean energy) is included in our search for solutions, then on-farm biogas units become an option. These facilities recycle wastes from livestock, thereby



preventing runoff of antibiotic residuals from farmland. They also partly destroy these residuals, while producing methane, a renewable and usable fuel (Mohring et al. 2009). Hence, an action to advance Goal 7 helps reduce the risk of AMR and advances Goal 2, while also supporting the water quality target. In this case the water quality target is the beneficiary of a synergy among goals.

## Discussion

### *What are the characteristics of interlinkages?*

The literature provides evidence of numerous interconnections between water quality and topics covered by SDGs (Table 1). Most of these are inferred since “water quality” or related concepts do not appear frequently in the SDG text. Table 1 shows that most interlinkages are potential synergies, broadly consistent with the results in UN-Water (2017). A predominance of synergies over trade-offs was also found by Griggs et al. 2017 for interactions between SDGs 2, 3, 7, and 14 and other SDGs. However, the IPCC found a mixed picture when they analysed the interactions between climate actions and other SDGs (Roy et al. 2018).

The predominance of synergies among water quality interlinkages shows that much can be achieved by taking actions to simultaneously advance the water quality and other targets. It also shows the importance of “Nexus”-type policy approaches that focus on the connections among, for example, water, land, and waste (Hülsmann and Ardakanian, 2018).

Although synergies predominate, some trade-offs do exist between water quality and the SDGs. The Case Studies illustrate some of these, but also show how a range of options can minimise them. The number of options becomes larger when the boundaries of the system being considered are expanded. For example in Case Study 4, the option of building more on-farm biogas plants to lessen the risks of AMR becomes apparent after widening the system boundaries to look outside of the health care – water environment system.

The case studies showed that interlinkages operate over a wide range of scales: municipal, river basin, and large region/near-global. The interlinkages are also directional, in that they have an identifiable driver. Also, water quality can play different roles. In Case Study 1, the interlinkage between water quality and energy use is driven by the assumption that more wastewater treatment plants will be built to achieve the water quality target. In Case Study 2, the driver is the expected increase in irrigated food production to meet Goal 2 (Zero hunger). An increase in food production worsens salinity pollution which sets up a trade-off with the water quality target. In Case Study 3, the driver is expanding bioenergy cropping to meet Goal 7 (Affordable and clean energy) which hinders the conservation of the marine environment embodied in Goal 14, with water quality acting as an intermediary. Finally, in Case Study 4, one driver is the target for health protection (Goal 3) leading to greater health care of humans, and the other is reducing hunger to zero (Goal 2) leading to an increase in the production of livestock and aquaculture-grown fish; under business-as-usual conditions, these will lead to higher antibiotic use and contamination of surface waters with antibiotics and resistant bacteria that hinder the achievement of the water quality target. We also saw in Case Study 4 that certain actions lead to synergies that benefit the water quality target.

Hence, water quality plays many different roles in SDG interlinkages – as driver, as intermediary, as loser in a trade-off situation, or as beneficiary of a synergy.

### ***How can the significance of interlinkages be assessed?***

Considering the large number of interlinkages identified in this paper, it would be helpful to provide policymakers and stakeholders with a ranking they can use to set priorities. Unfortunately, the literature does not provide enough evidence to make this ranking, especially because different metrics are used to describe the significance of interlinkages. As an example, it is difficult to compare the importance of interlinkages between Case Studies 1 and 2 when one metric is the “fraction of electrical use in a particular municipality for wastewater treatment” and the other is “the stretch of rivers with salinity exceeding the level for safe irrigation use”.

An obvious strategy to reconcile such differences is to use expert judgement, which has been the main approach used to assess and rank SDG interlinkages up to now (Scharlemann et al. 2016; Griggs et al. 2017; UN-Water, 2017).

While using expert groups is a pragmatic and useful way to assess interlinkages, it can be made even more useful in two ways. First, the transparency and credibility of these assessments would be enhanced if explicit protocols were used to solicit the views of experts (e.g. Hemming, 2018). Second, to enhance the legitimacy of expert groups they should be authorized by an appropriate national or international institution and consist of not only scientific experts, but also representatives from the private sector, international organizations, poor communities (“Leave no one behind”) and others with a stake in the global goals.

Another promising approach for assessing interlinkages are techniques used for valuating ecosystem services (Grizzetti et al. 2016). Appraisals of ecosystem services have similarities to appraisals of SDG interlinkages in that they both involve objects that have great variations in spatial and temporal scales, coverage, and perceived value.

Integrated modelling is also a potential tool for identifying water quality interlinkages. Here, the major technical challenge will be to develop reliable large-scale water quality models that can be incorporated into existing large scale integrated models.

Although this paper does not attempt to rank the interlinkages, the case studies suggest that their significance overall will increase over the period of SDG implementation. Under business-as-usual conditions, the energy requirements for wastewater treatment are expected to increase; salinity pollution will worsen because of expanding irrigated land; eutrophied coastal zones will further expand due to the growth in bioenergy and other cropping, antibiotics will reach higher levels in rivers because of growing antibiotic use. These trends, with the possible exception of expanding bioenergy cropping, will be particularly important in developing countries.

### ***What is the suitability of SDG indicators for tracking water quality interlinkages?***

A precondition for taking action on synergies or trade-offs is a capability to monitor interlinkages. For example, if policies and measures are to be taken to reduce the release of antibiotics into the water environment, then it is important to monitor their presence in rivers and other waterways. (On the other hand, the larger the number of indicators, the larger the amount of resources needed to track these indicators.)

The question then arises, are the “official” indicators (i.e. the indicators agreed to by the Parties to the SDGs for the water quality target), adequate for tracking the interlinkages? These indicators (IAEG-SDGs, 2017) are:

- Proportion of wastewater safely treated

- Proportion of bodies of water with good ambient water quality

A further question is, how to define “good ambient water quality” in the second indicator? UN-Water (2018a and b) has proposed the following “core parameter set”: dissolved oxygen, electrical conductivity, nitrogen, nitrate, phosphorus, pH.

Table 1 indicates where these indicators and parameters are applicable, in principle, for monitoring water quality interlinkages. For instance, the core parameters can be used to track the impact of agriculture on water quality of surface waters (Table 1, under Goal 2). But being applicable is not the same as being adequate for this purpose. Tracking the impact of agriculture, for example, requires the measurement of other parameters such as pesticide and other chemical residues in the water environment. Monitoring Target 6.6 (to “protect ... water-related ecosystems ...”) also requires the measurement of ammonia, trace toxic substances, and many other parameters; tracking Goal 13 (Climate action) should include, at a minimum, water temperature.

Even bigger gaps occur for other interlinkages. For instance, monitoring the interconnections of the water quality target with Target 3.3 (“combat hepatitis, water-borne diseases and other communicable diseases”), Target 3.9 (substantially reduce the number of deaths and illnesses from ... water pollution and contamination”), and Target 6.1 (achieve “safe ... drinking water”) requires measurements of pathogens, antimicrobial substances, arsenic, and many other parameters related to health risk, none of which are included in the core parameter set. The most relevant parameter from the core set is nitrate which can be used to monitor health risk from nitrogen seepage into groundwater.

On the other hand, these limitations are not surprising since UN-Water (2018a and b) makes it clear that the core parameters were selected because they are “simple to measure and are a good starting point for countries with less-developed monitoring capacities”. Nevertheless, high priority should be given to closing the gaps in official indicators and parameters by bolstering capabilities for water quality monitoring in developing countries. Otherwise it will not be possible to effectively track progress towards either the water quality target or its many interlinkages with other SDGs.

## Conclusions

- This paper presents an extensive (yet not exhaustive) inventory of the interlinkages between the water quality target and other SDG targets, based on evidence from the literature (Table 1). Many more synergies than trade-offs were identified which provides an opportunity for policies and measures across the SDG sectors that would simultaneously advance the water quality and other targets.
- Most of the synergies were inferred rather than explicit which means that most of them are not included in the text of the SDGs (Table 1). It is also then unlikely that they are being considered within the political process to implement the SDGs. Therefore, their importance should be brought to the attention of the policy community.
- Based on the case studies examined, interlinkages operate from the municipal to near-global scale, and are expected to intensify, especially in developing countries. The case studies also illustrate the many possible interventions for minimizing the impacts of trade-offs and realizing synergies. Widening the systems boundary helps identify more solutions to trade-offs. The case studies also showed that interlinkages are directional and that water

quality plays many different roles in them, sometimes being a driver, an intermediary, a loser in a trade-off situation, or a beneficiary in a synergy situation.

- Although expert assessment is a pragmatic and useful way of assessing the importance of interlinkages, assessment procedures should be made more transparent, credible and inclusive. Related to assessment, there is a large, important gap in official indicators for tracking water quality interlinkages. In particular, indicators are needed for monitoring the connection between health and water quality targets, including the presence of pathogens and residuals of antimicrobial agents in the water environment.
- The analysis of water quality interlinkages shows that policymakers, stakeholders, and researchers concerned with water quality have many potential allies in other parts of the SDG community. Joining forces with these new allies can increase the resources available to achieve both the water quality target, and many other targets under the SDGs.

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Table 1. Overview of interlinkages between SDG water quality target (6.3) and other targets in the Sustainable Development Goals. Not an exhaustive listing.

SDG	Interlinkage of water quality target with underlying targets of indicated goal	Explicit or inferred interlinkage?	Trade-off or synergy?	Applicable water quality indicator  (From official indicators for water quality target and core parameter set proposed by UN-Water. See text.)
1. No poverty	<p>Targets under SDG 1 aim to “build resilience of poor” and ensure that the poor have “access to basic services”, among which clean water is very important. (Sullivan, 2002).</p> <p>But there is complex relationship between economic well-being and water quality and, by implication, between water quality and actions to reduce poverty. According to the Environmental Kuznets Curve, the volume of untreated discharge of many important water pollutants increases with increasing per capita income, up to a certain point, and then declines because of investments in wastewater treatment and other measures. This relationship has been confirmed by some researchers (Lin and Liscow, 2014). This implies that the interlinkage between water quality and poverty becomes more important as more people escape poverty and stimulate greater pollution-causing economic activity up to a certain point.</p> <p>Other research points to a more complex “wave” relationship between economic development and the volume of wastewater discharges. (Zhang and Gangopadhyay, 2015).</p> <p>Hence, actions to reduce poverty may set up a trade-off or synergy relative to water quality, depending on business-as-usual circumstances.</p>	Inferred	Undetermined	Proportion of wastewater safely treated
2. Zero hunger	<p>Water pollution may increase or decrease depending on the choice of strategy to eliminate hunger and malnutrition (Targets 2.1 and 2.2) and implement agricultural policies (Targets 2.3 to 2.6):</p> <p>Water quality of surface waters and groundwaters are likely to be degraded if more food is produced via expansion or intensification of cultivated land (Targets 2.1 and 2.2). . (Mateo-Sagasta et al. 2017) This will set up a trade-off between reducing hunger and water quality</p> <p>However, Target 2.3 aims to promote “sustainable food production systems” which presumably will encourage actions to protect water quality, and hence promote a synergy between reducing hunger and water quality. For example, a more sustainable food system would lead to a reduction in food system waste and loss and thereby produce more food from the same agricultural inputs, and tend to reduce the runoff of nitrogen and other pollutants from agriculture. (Grizetti et al. 2013).</p>	<p>Inferred</p> <p>Inferred</p> <p>Inferred</p>	<p>Trade-off</p> <p>Synergy</p> <p>Synergy</p>	<p>DO, EC, N, NO<sub>3</sub>, P, pH (dissolved oxygen, electrical conductivity, nitrogen, nitrate, phosphorus, pH)**</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>DO, EC, pH</p>

SDG	Interlinkage of water quality target with underlying targets of indicated goal	Explicit or inferred interlinkage?	Trade-off or synergy?	Applicable water quality indicator  (From official indicators for water quality target and core parameter set proposed by UN-Water. See text.)
	Good water quality is also an important prerequisite of subsistence fishing (Adeyemo, 2003) (related to hunger and malnutrition Targets 2.1 and 2.2)			
3. Good health and well-being	Explicit connection with Target 3.3 (“combat hepatitis, water-borne diseases and other communicable diseases”)	Explicit	Synergy	None
	Explicit connection with Target 3.9 (substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination”) because consumption of, or contact with, contaminated water (pathogens, toxics) is a major source of disease and illness. (Prüss-Ustün, A. et al. 2014). Therefore, improving health care requires good quality water.	Explicit	Synergy	NO <sub>3</sub>
	An important emerging issue is the over-use of antibiotics (especially related to Targets 3.1, 3.3, 3.4, 3.8, 3.b) to fight disease resulting in the build-up of antimicrobial resistance. Antibiotic residuals and resistant bacteria are observed in freshwaters. As health care expands, antibiotic use will increase under business-as-usual assumptions. See Case Study 4.	Implicit	Trade-off	None
4. Quality education	The education targets especially Target 4.7 (“...ensure that all learners acquire the knowledge and skills needed to promote sustainable development”) will help achieve the water quality target.  For example, there is some evidence that hygiene education reduces the risk of experiencing intestinal diseases (McDonald et al. 2008), and that public education increases engagement and support of citizens for water pollution programmes (e.g. Dietz et al. 2004).	Inferred	Synergy	None
5. Gender equality	Gender equality has in important connection to water quality, e.g. Target 5.1 (“End all forms of discrimination”) and Target 5.4 “Promotion of shared responsibility within the household”) and Target 5.c (“Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels”).  The connection with the water quality target arises because women in rural societies are often particularly responsible for water supply in the household (e.g. Manase et al. 2003), and at risk of coming into contact with polluted surface waters (e.g. Manyanhaire, et al. 2009).  Therefore, women are major stakeholders in the achievement of good water quality and their support is needed if water quality programmes are to be successful in developing and other countries.	Inferred Inferred Inferred	Synergy Synergy Synergy	None None None
6. Clean water and sanitation	Water quality (Target 6.3) has essential self-evident links to the other targets in Goal 6:  Target 6.1 (achieve “safe ... drinking water”)  Target 6.2 (“achieve access to adequate and equitable sanitation and hygiene for all and end open defecation”)	Explicit  Explicit	Synergy  Synergy	NO <sub>3</sub>  None

SDG	Interlinkage of water quality target with underlying targets of indicated goal	Explicit or inferred interlinkage?	Trade-off or synergy?	Applicable water quality indicator  (From official indicators for water quality target and core parameter set proposed by UN-Water. See text.)
	<p>Target 6.4 (“to “ensure sustainable withdrawals and supply of freshwater”</p> <p>Target 6.5 (to “implement integrated water resources management”</p> <p>Target 6.6 (to “protect ... water-related ecosystems ...”</p> <p>Target 6.7 (to “expand ... cooperation ... in water- ... related activities”</p> <p>Target 6.a (to “expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies</p> <p>Target 6.b (“to “support ... participation of local communities in improving water and sanitation management.”)</p>	<p>Explicit</p> <p>Explicit</p> <p>Explicit</p> <p>Explicit</p> <p>Explicit</p> <p>Explicit</p>	<p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p>	<p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH ?</p> <p>Proportion of wastewater safely treated</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH ?</p>
7. Affordable and clean energy	<p>Depending on the future mix of energy (especially how bioenergy is employed), the following targets may lead to an increase or decrease in water pollution. (e.g. Diaz-Chavez et al. 2011).</p> <p>Target 7.1 (“ensure ... access to ... modern energy services”)</p> <p>Target 7.2 (“increase ... the share of renewable energy”)</p> <p>Target 7.a (“enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology”),</p> <p>Target 7.b (“expand infrastructure ... for supplying modern ... energy services”)</p> <p>If bioenergy is part of the renewables mix then impacts on water quality are likely to occur at various points in the its supply chain. For example, N runoff from bioenergy crops is linked to coastal eutrophication in the US. (Alexander et al. 2008). See Case Study 3 in this paper.</p> <p>All else being constant, Target 7.3 (“improving energy efficiency”) would decrease impacts on water quality because the energy system would produce proportionately less water pollutants and its other impacts such as thermal discharges into rivers would also presumably decrease. However, a change in the energy mix could negate the improvements in water quality.</p> <p>As the capacity for wastewater treatment increases (Target 6.3) the demand for energy will also increase at the municipal level (WWAP, 12). See Case Study 1 in this paper.</p>	<p>Inferred</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p>	<p>Undetermined</p> <p>Undetermined</p> <p>Undetermined</p> <p>Undetermined</p> <p>Trade-off</p> <p>Undetermined</p> <p>Trade-off</p>	<p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>None</p> <p>None</p> <p>DO, N</p> <p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>None</p>
8. Decent work and economic growth	There is a general link between this goal and water quality in the sense that the total discharged volume of untreated or partially-treated wastewater tends to increase with economic indicators up to a certain economic level. Depending on the level of wastewater treatment and other factors, water quality will either improve or deteriorate. See Goal 1.	Inferred	Undetermined	Proportion of wastewater safely treated

SDG	Interlinkage of water quality target with underlying targets of indicated goal	Explicit or inferred interlinkage?	Trade-off or synergy?	Applicable water quality indicator  (From official indicators for water quality target and core parameter set proposed by UN-Water. See text.)
	<p>There is a connection with Target 8.4 (improve resource efficiency) and water quality because as efficiency improves, fewer materials per service are used, and wastewater produced per service is also likely to decrease. This relationship has been verified as part of “Cleaner Production” research (e.g. Nilsson et. al, 2007)</p> <p>Also, there is a likely synergy between good water quality and Target 8.9 (“promoting sustainable tourism”) which will promote practices to lower pollution.</p> <p>There is also a linkage between water quality and trade (8.a) since trade involves a shift in the location of economic activities that have undetermined water pollution and other environmental impacts.</p>	<p>Inferred</p> <p>Inferred</p> <p>Inferred</p>	<p>Synergy</p> <p>Synergy</p> <p>Undetermined</p>	<p>Proportion of wastewater safely treated?</p> <p>None</p> <p>None</p>
9. Industry, innovation and infrastructure	<p>In principle, it is expected that water pollution will decrease with:</p> <p>Target 9.1 (“Develop quality, reliable, sustainable and resilient infrastructure”)</p> <p>Target 9.2 (“Promote inclusive and sustainable industrialization”)</p> <p>Target 9.4 (Upgrade infrastructure and retrofit industries to make them sustainable”)</p> <p>Target 9.a (“Facilitate sustainable and resilient infrastructure development in developing countries”)</p> <p>But wording of text vague, and no explicit evidence found in literature.</p>	<p>Inferred*</p> <p>Inferred*</p> <p>Inferred*</p> <p>Inferred*</p>	<p>Synergy*</p> <p>Synergy*</p> <p>Synergy*</p> <p>Synergy*</p>	<p>None</p> <p>None</p> <p>None</p> <p>None</p>
10. Reduced inequalities	<p>Perhaps a connection with Target 10.b “Encourage ... development assistance and financial flows ... to States where the need is the greatest.” This aid can be used, in principle, for water pollution control and management.</p> <p>But no evidence found in literature.</p> <p>Gender inequality addressed under Goal 5.</p>	<p>Inferred*</p>	<p>Synergy*</p>	<p>None</p>
11. Sustainable cities and communities	<p>Consistency between water quality target (e.g. Haddis et al. 2014; Donifiro et al. 2009) and the following:</p> <p>Targets 11.1 (“upgrade slums”), 11.2 (“expanding public transport”) 11.3 (“enhance ... sustainable urbanization”).</p> <p>Target 11.5 (reducing the number of deaths and number of people affected by water-related disasters”) assuming this includes. chemical spills in cities.</p> <p>Target 11.6 (“reduce the adverse per capita environmental impact of cities”).</p> <p>Target 11.a (“support positive environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning”)</p> <p>Target 11.b (“ increase the number of cities adopting integrated policies towards resource efficiency”)</p> <p>Target 11.c (sustainable ... buildings)</p>	<p>Inferred</p> <p>Explicit</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p>	<p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p>	<p>None</p> <p>None</p> <p>None</p> <p>None</p> <p>None</p> <p>None</p>
12. Responsible consumption and production	<p>General agreement in literature that sustainable consumption and production practices can lead to better water quality, if quality is not already high (e.g. Tsuzuki, 2014)</p>			
	<p>Indirect connection (except for 12.4) between water quality and the following targets:</p> <p>Target 12.1 (“implementing the 10-Year Framework”)</p>	<p>Inferred</p>	<p>Synergy</p>	<p>None</p>

SDG	Interlinkage of water quality target with underlying targets of indicated goal	Explicit or inferred interlinkage?	Trade-off or synergy?	Applicable water quality indicator  (From official indicators for water quality target and core parameter set proposed by UN-Water. See text.)
	Target 12.2 (achieving efficient use of natural resources ) Target 12.3 (“halving global food waste”) and thereby proportionally reducing the impact of agriculture on water pollution	Inferred Inferred	Synergy Synergy	None None
	Target 12.4. (“achieving environmentally sound management of chemicals and significantly reducing their release to ... water”)	Explicit	Synergy	Proportion of wastewater safely treated
	Target 12.5 (“substantially reducing waste generation”)	Inferred	Synergy	Proportion of wastewater safely treated
	Target 12.6 (“encourage companies to adopt sustainable practices) which would presumably reduce wastewater production”	Inferred	Synergy	Proportion of wastewater safely treated
	Target 12.7 (“promote sustainable public procurement practices” which would presumably reduce the amount of “harmful materials finding their way into wastewater”).	Inferred	Synergy	None
	Target 12.8 (“ ensure people have relevant information for sustainable development”)  Target 12a. In general sense, water quality should improve if countries receive support to strengthen their scientific capacity to move towards sustainable consumption  Target 12b. implement tools to monitor sustainable development impacts	Inferred Inferred Inferred	Synergy Synergy Synergy	None None None
13. Climate action	Previous studies indicate that impacts of climate on water quality depend on particular regional changes in climate and characteristics of water systems.  With regards to precipitation changes, if the climate becomes drier, then there will be less dilution capacity in rivers, but also less overland runoff of pollutants into rivers. If the dilution effect predominates, then drier climates will experience a worsening of surface water quality. If the climate becomes wetter, then there might be more overland pollutant runoff, but greater dilution capacity. Despite this uncertainty, some regions will undoubtedly experience a worsening of water quality due to precipitation changes. (Delpa et al. 2009)  Climate impact is clearer with regards to temperature changes: global warming increases water temperature which has various negative impacts on aquatic ecosystems. (Punzet et al. 2012)  Hence, climate mitigation will, in general, tend to reduce impacts on water quality, leading to a synergy between climate targets and the water quality target.	Inferred	Regionally variable, but globally a synergy	DO, EC, N, NO <sub>3</sub> , P, pH (Gap: Water temperature)
14. Life below water	Connection with Target 14.1 (reducing marine pollution, especially from land-based activities including nutrient pollution) (14.1) because poor inland water quality (nitrogen pollution) sometimes causes coastal hypoxia zones and endangers the environmental quality of coastal conservation areas. See Case Study 3.	Explicit Inferred	Synergy Synergy	N, DO, Proportion of wastewater safely treated? N, DO, Proportion of wastewater safely treated?

SDG	Interlinkage of water quality target with underlying targets of indicated goal	Explicit or inferred interlinkage?	Trade-off or synergy?	Applicable water quality indicator  (From official indicators for water quality target and core parameter set proposed by UN-Water. See text.)
	<p>For the above reason there is also a connection, but more indirect, with Targets 14.2 (sustainably managing marine and coastal ecosystems) and 14.5 (“conserving at least 10 percent of coastal areas”)</p> <p>In principle ocean acidification is a water quality issue since acidity is a water quality attribute, so there should be a connection with Target 14.3 (reducing ocean acidification). However, the main cause of ocean acidification is carbon dioxide from the atmosphere.</p> <p>Connection with Target 14.7 between water quality and sustainable management of aquaculture and tourism (because these are major sources of water pollutants in the coastal zone). (Reopanichkul et al. 2010)</p>	<p>Explicit</p> <p>Inferred</p>	<p>Weak synergy</p> <p>Synergy</p>	<p>pH</p> <p>DO, N, P, pH</p>
15. Life on land	<p>Since water quality is an essential attribute of freshwater ecosystems, there is explicit connection with Target 15.1 “ensure the conservation, restoration and sustainable use of ... inland freshwater ecosystems and their services”</p> <p>Connection with Target 15.2 “implementation of sustainable management of all types of forests” because some forms of conventional forestry lead to sediment loss and contamination of surface waters. (Croke and Hairsine, 2006.)</p> <p>Connection with Target 15.3 “combat desertification, restore degraded land and soil” because good soil condition helps maintain good water quality above and below-ground. (e.g. Sahrawat et al. 2010).</p> <p>Connection with Target 15.5 “prevent the extinction of threatened species” because water pollution is a contributor to species extinction (e.g. Borzee et al. 2018).</p> <p>Connection with Target 15.9 “integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts” and 15a and 15b (“mobilize ... resources”) because water quality is an important “ecosystem value” (e.g. Keeler, et al. 2014).</p>	<p>Explicit</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p> <p>Inferred</p>	<p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p> <p>Synergy</p>	<p>DO, EC, N, NO<sub>3</sub>, P, pH</p> <p>None?</p> <p>None</p> <p>DO, EC, pH</p> <p>None</p>
16. Peace, justice, strong institutions	<p>Connection with Targets 16. 1(“Significantly reduce all forms of violence”) and 16.3 ( “Promote the rule of law”) because degradation of water quality can be a source of conflict between parties (e.g. Evensen and Stedman, 2018), while agreements to mutually protect water quality can contribute to peace between them (e.g. Fischhendler et al. 2014). Either way, advancing the water quality target might contribute to conditions that reduce violence and conflict between parties sharing water resources by making more good quality water available to these parties.</p> <p>Corruption can affect water governance through misappropriation of water management resources and failure to enforce water protection regulations. The result can be uncontrolled water pollution. (Ezbakhe, 2018). Therefore, reducing corruption might contribute to more effective water management.</p>	<p>Inferred</p> <p>Inferred</p>	<p>Synergy</p> <p>Synergy</p>	<p>None</p> <p>None</p>
17. Partnerships for the Goals	Connection with water quality because partnerships can facilitate or enable successful programmes to protect water quality (e.g. Peckenham, 2006)	Inferred	Synergy	None

\* No literature is cited in this paper to support this assertion

\*\* This is the core parameter set proposed by UN-Water (2018a and b) for monitoring “ambient water quality” under the SDG water quality target.